National Aeronautics and Space Administration

Technology, Innovation, & Engineering Committee
of the
NASA Advisory Council

Virtual Meeting
March 19, 2020

Meeting Minutes

G. Michael Green, Executive Secretary

James Free, Chair

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Meeting Report prepared by
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Welcome and Overview of Agenda/Logistics
Mr. G. Michael Green, Executive Secretary of the NASA Advisory Council (NAC) Technology, Innovation, and Engineering (TI&E) Committee, welcomed the Committee members. While this was a virtual meeting due to the coronavirus pandemic, it was also public, and everything was on the record.

Opening Remarks
Mr. James Free, TI&E Chair, thanked Mr. Green and the Committee members for their time.

Space Technology Mission Directorate (STMD) FY 2021 Budget Proposal and Update
Mr. James Reuter, Associate Administrator of NASA's Space Technology Mission Directorate (STMD), explained that his presentation included all of the slides from the briefing he gave to Congress at the end of February, after the President's Budget Request (PBR) for Fiscal Year 2021 (FY21) came out. Some of those slides were back-ups they could read on their own. As the coronavirus situation spools out, it will affect some of the dates presented, and the NASA centers were all on mandatory telework, so many activities would stop. A few projects with critical elements would follow a set of rules for those elements.

STMD work spans the Technology Readiness Levels (TRLs), from early stage innovation through technology maturation, technology demonstrations, and technology transfer. The strategic framework has four thrusts: Go, Land, Live, and Explore. Each is semi-quantitative and shows the capabilities that need to be pursued. An overarching thrust is to lead in the direction of commerce.

The investment strategy starts with delivering technologies to enable a sustainable Moon-to-Mars presence. This involves work on propulsion, demonstration of precision landing and hazard avoidance technologies with Commercial Lunar Payload Services (CLPS) partnerships and suborbital launch providers, and the development of long-term cryogenic storage capability with very low boiloff rates. An area of particular focus is the creation of novel technologies needed for lunar surface exploration. This will be done via the Lunar Surface Innovation Initiative (LSII), and will involve such fields as in situ resource utilization (ISRU); surface power development, including regenerative fuel cells and nuclear fission power reactor; and additional technologies to address dust mitigation, excavation, construction, surface robotic scouts, and more. Some of these are targets for the late 2020s. In the meantime, STMD will continue work on the Laser Communications Relay Demonstration and the Deep Space Atomic Clock (DSAC), while continuing to use the International Space Station (ISS) as a testbed.

Mr. Free said it appeared that anything developed for the lunar surface will go through LSII. Mr. Reuter explained that LSII is an initiative that goes beyond getting humans landed on the Moon; it has six categories, and there was to be a presentation on it later in the meeting. The STMD investment strategy also calls for STMD to use its entire portfolio and its partnerships to enable the Moon-to-Mars effort, while enhancing space commerce. This will involve direct partnerships with companies competing to provide the requisite capabilities. To that end, there are Tipping Point solicitations out in three categories, where STMD intends to invest approximately $250 million. STMD issued 19 Announcement of Collaborative Opportunities (ACO) non-reimbursable Space Act Agreement (SAA) awards in the summer of 2019. For LSII, STMD will use a University Affiliated Research Center (UARC) as the system integrator and form a Lunar Surface Consortium that pulls in industry, academia, and NASA expertise. The kick-off for the Consortium occurred recently.

Early Stage Innovation investments are growing, as TI&E had recommended. The Early Career Initiative (ECI) has been very successful, and STMD has continued the Space Technology Research Grants (STRGs). The Directorate is pursuing technology payload demonstrations on CLPS and the Lunar Gateway. There is now some flexibility in the use of Small Business Innovation Research (SBIR) funds. The SBIR budget tracks overall NASA budget growth.

STMD will be demonstrating in-flight mission servicing of the Landsat mission with the restructured Restore-L mission. There will also be investments in unique and appropriate technologies to prepare for human exploration of Mars. Among these activities are assessments of Entry, Descent, and Landing (EDL) and vehicle systems to inform the Moon-to-Mars campaign. As yet, there has been no selection of a Mars transportation architecture. STMD will also pursue a new space nuclear power and propulsion effort, and to that end, has initiated a 15-month National Academy of Sciences (NAS) study comparing propulsion options. These will include both nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP) concepts. A flight demonstration of the selection is required by law. Mr. Michael Johns asked about surface power. Mr. Reuter said that it would be similar to the kilopower system discussed at previous meetings. The difference here is that the original system was sized to 10KW; while the lunar system has a target of 40KW, the plan is to start with 10KW in order to have redundancy. There will be another down-selection, and NASA will determine whether it can make a system compatible with low-uranium fuel options.

There may be changes to Artemis phases, but STMD will stay on the test path. The Moon-to-Mars chart of the Go, Land, Live, Explore phases illustrates how the Moon is a good proving ground for the Mars campaign. Not all capabilities will carry forward, but many lend themselves to lunar work.

In the budget chart, the enacted appropriations for FY20 were blocked out because the operating plan was still being finalized. There will be substantial growth in STMD's FY21 budget, to $1.6 billion from FY20's $1.1 billion. There is substantial growth in SBIR/Small Business Technology Transfer (STTR) from FY19 through FY21. These two fiscal years are the peak budget years, reflecting delivery schedules for Solar Electric Propulsion (SEP), Deep Space Optical Communications (DSOC), and others. There are some cost challenges, and those are being addressed. This budget proposal consolidates the technology maturation and technology demonstration budgets for both Cryo Fluid Management (CFM) and Space Nuclear Technologies (SNT). Mr. Free asked if the SNT line put STMD on a path for a flight surface system demonstration. Mr. Reuter said that that was the case, with a target of the late 2020s, and part of that goes to developing the flight path for a nuclear propulsion system. Mr. Free asked about operational funding for DSOC. Mr. Reuter replied that some of the FY22 funding was for that plus integration.

STMD has tried to delineate which parts of the investments fit under the Moon, Mars, cross-cutting, and commerce areas. The goal, which should be obvious in the out-years, is to be at about 75 percent Moon-to-Mars. In FY19, that was more like 45-50 percent, and the reason for that is Restore-L, aimed at satellite servicing. While the Agency still hopes to pursue in-space satellite servicing, priorities shift. NASA will follow the appropriations.

STMD has four budget control accounts: SBIR/STTR; Early Stage Innovation and Partnerships; Technology Maturation; and Technology Demonstration. STMD is adding lunar surface innovation research opportunities in the ECI area. These will be 2-year projects, and the goal is to select nine this year. Each center is targeted to have one selection per year, in order to both support early career growth and develop excellent technologies. Technology Maturation includes Tipping Point and other activities. Technology Demonstration has an increased FY21 budget compared to FY19, but a decrease from FY20. Mr. Reuter then listed a number of upcoming activities. STMD will be demonstrating, then commercializing, some of these technologies. The schedule may slip for the Blue Origin precision landing technology flight test.. Composite technology work has been successful thus far. The Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) heat shield has been delivered. The Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) is a consortium at NASA's Marshall Space Flight Center with multiple industry partners.

The space nuclear system portfolio is an area STMD wanted to emphasize with Congress. The Defense Advanced Research Projects Agency (DARPA) is interested in some of these efforts, as are other parts of the U.S. Department of Defense (DOD). STMD wants to bring this together and show why there is so much interest in fission surface power as the first application, as opposed to NTP. A Mars fission surface power system is likely to have substantially less mass and significantly more reliability than a solar power system, and a fission system demonstration on the Moon will be directly applicable to human exploration of Mars. There are essentially two ways to get to Mars. The first class of missions, conjunction-class, would require alignment of Earth and Mars, necessitate that the missions stay at Mars at least 500 days, and result in missions of about 1,000 days. Opposition-class missions would enable somewhat shorter missions of about 700 days while allowing short stays at Mars. The Agency wants an NTP system that can enable opposition-class missions. Traditionally, NTP has been considered simpler, but the performance needs are not enabling of all opposition-class missions. It is looking like it would be a harder system to design, so NASA has asked NAS to study NEP, as it appears that a hybrid NEP/chemical system could be viable and require less technology investment. There are overlaps with DOD and DARPA work. The point is that NASA is not ready to downselect, and instead needs more technology investment and development.

Mr. Reuter gave the projected budgets for nuclear fission power and nuclear propulsion. NASA and the U.S. Department of Energy (DOE) are doing a joint study of nuclear fission power design; Mr. Reuter detailed the responsibilities for each agency. They would like to get to mid-size landers, if possible. Flight demonstration options for NTP systems are FD-1, which is schedule-driven, and FD-2, which is capabilities-driven. Both are being assessed. FD-1 might be able to be demonstrated by 2024-25 using current technologies and a non-representative scale. However, FD-1 would not be extensible to the Mars architecture despite an estimated cost of around $1 billion. This assessment led NASA to conclude that it did not warrant further examination by an industry team. FD-2 is being assessed by separate NASA-led and industry-led teams; both studies should be finished by April, though the out-brief was being rescheduled.

Mr. Reuter next discussed the Go, Land, Live, Explore phases. For Go, he noted the SEP activities. The thruster is looking good. The Green Propellant Infusion Mission (GPIM) was launched last June and is virtually non-toxic. That mission will be completed by the end of FY20. For Land, the Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE), being done at NASA's Langley Research Center, is being commercialized. An EDL chart shows items critical for the Moon and Mars, all of which help to improve models and data. The Live phase was to be covered in the LSII briefing later in the TI&E meeting. Explore had been mostly discussed. DSAC flew last year and is working better than hoped, with stability an order of magnitude better than targeted. Archinaut is small spacecraft in which STMD will demonstrate the manufacturing of a boom and assembly of a solar array in orbit. That is at about the Critical Design Review (CDR) phase.

On-orbit Servicing Assembly and Manufacturing 1 (OSAM-1) combines satellite servicing and SPace Infrastructure DExterous Robot (SPIDER) objectives to qualify advanced technologies that will help extend the useful lives of on-orbit satellites. A number of technology areas need to be qualified. Mr. Reuter noted the status of the project, with segments having been through CDR, and SPIDER having had its Performance Design Review (PDR). The next milestone on the schedule was mission CDR, for September 2020, through SPIDER payload delivery to the spacecraft bus in FY23. SPIDER will manufacture a 10-meter boom and assemble a 3-meter antenna to demonstrate the robotic build of large in-space structures. Launch is planned for FY24.

There are ample opportunities for academia and industry. He expects there to be about $600 million for solicitations. In answer to a question about collaborations on satellite servicing, Mr. Reuter said that Northrop Grumman had a great demonstration that showed a simplified way of providing service and capabilities. This is in partnership with DARPA, and enhancements are planned. While NASA is so far along that it would be hard to pull in new partners, the Agency could benefit from the lessons learned at DARPA and is communicating with the project about that. He described the STRG proposal opportunities. There will be new opportunities to propose for short-duration, high-value grants through the Lunar Surface Technology Research (LuSTR) solicitation expected to be released this summer.

Mr. Reuter summarized his presentation by providing data on proposals, partnerships, and projects. Mr. Free thanked him for explaining the way the nuclear work is coming together. He believed STMD had a good path for evaluating technologies for surface and propulsion purposes. He would like to see the data on technology transition, commercial involvement, and patent licensing. Mr. Reuter said he could do that for the next meeting. In answer to another question, he said that the STRGs are funded at $50 million this year and could grow to $70 million next year. The NASA Innovative Advanced Concepts (NIAC) are close to evenly funded among industry, academia, and government.

Space Technology on ISS Update and Lunar Surface Innovation Initiative (LSII) Update

Ms. Niki Werkheiser is the Game Changing Development (GCD) Program Executive and LSII Lead. She began by discussing technology testing on ISS.

ISS Update

ISS has been an incredible testbed, helping to reduce risk and address operational challenges. It provides a critical capability for human and robotic space exploration beyond Low Earth Orbit (LEO). Key technologies tested include fluid transfer, in-space manufacturing and assembly, biologicals, materials, food production, and the Environmental Control and Life Support System (ECLSS). Regarding lessons learned, HEOMD has evolved some tools for payload user handbooks and the like. NASA works with principal investigators and universities on their ISS payloads, there are interfaces and testing that have evolved, and an increasing number of documents, user guides, and forums have come up over the years. Mr. Reuter added that as NASA moves to the CLPS landers, it is more complex than the suborbital work that has been done over time, and yet there are more providers. Ms. Werkheiser said that there are comprehensive phone surveys conducted after the payloads are done. HEOMD takes the input to evolve the user guides and forums.

Ms. Werkheiser gave some examples of STMD technologies on the ISS. Various contracts and procurement mechanisms have been key in enabling diverse ways of operating with a wide range of partners. The project on 3D printing in zero gravity was operated in the microgravity glovebox. There was a lot of public interest in this, as it was an easy concept for people to grasp. The Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) investigation examined fluid slosh in a microgravity environment. The Phase Change Material Heat Exchanger (PCM-HX) uses wax as a hot coolant. CubeSat efforts include Integrated Solar Array and Reflectarray Antenna (ISARA) and TechEdSat-6. The Gecko-Gripper is a highly versatile hand tool. The Additive Manufacturing Facility (AMF), by Made in Space, Inc., is a commercial manufacturing platform designed to print 3D parts in microgravity. To date, it has produced more than 115 tools, parts, and other items on ISS. NASA redesigned the contract to accommodate the Made in Space needs, and is moving onto the next generation of AMF, which can use three different polymers. The Vibration Isolation Platform is a mounting interface that allows a payload to be undisturbed and float freely in the sway space of the platform. This originated with SBIR.

The Zero Boil-Off Tank was an important collaboration in an area of interest to STMD, demonstrating use of a volatile fluid that boils to simulate a cryogen, in order to test active heat removal and forced jet mixing as alternative means for controlling tank pressure for volatile fluids. STMD is using the results to improve tank design for long-term cryogenic fluid storage and pressure control. In answer to a question about CFM and the delays STMD experienced in having a flight demonstration, Mr. Reuter said that the Directorate may have been ahead of its time with this effort. The shift allows some refocusing. To get to 2024, STMD must emphasize systems that are at TRL 6 or greater, and CFM is not there. Further, it might not be needed until longer or expanded missions. It was a big step, even though the technology was not quite ready. It remains on the path to the Moon and Mars.

Ms. Werkheiser described the Station Explorer for X-ray Timing and Navigation Tech (SEXTANT), for which there are a lot of applications. It demonstrated a GPS-like absolute position determination capability by observing millisecond pulsars, which will enable autonomous navigation throughout the solar system and beyond. There are also projects related to CFM. Among these is the Robotic Refueling Mission 3 (RRM3), to demonstrate transfer and long-term storage of liquid methane in microgravity. There were issues with this demonstration that necessitated changes in the experiment. The altered RRM3 did teach NASA about the technology needed to store and transfer cryogenic fuel in space. The change affected the Radio Frequency Mass Gauge (RFMG), which was to determine the amount of cryogenic propellant in a tank while in low gravity or where slosh is an issue.

The impact of Intracranial Pressure (ICP) on astronauts' vision has been a concern. As part of the long-term work in this area, a University of Texas project measured ICP in volunteers who had a permanent port in their heads for cancer treatment. Astrobee comprises a series of free-flying robotic helpers that help ISS astronauts with routine tasks like maintenance and tracking inventory, while also maintaining a guest science research platform. The Refabricator is a 3D printer and recycler. It experienced a failure with the novel recycler filament extrusion bonding system in 2019; additional bonder testing is being conducted prior to decommissioning, and further testing on ISS is planned for 2020. Work with BioNutrients/Synthetic Biology addresses vitamin loss and the use of engineered microbes to create replacements. The Multi-material Fabrication Laboratory (FabLab) will be a space-based, multi-material, on-demand fabrication capability for long-duration missions.

The Materials International Space Station Experiments (MISSE) program includes a number of projects and planned ISS demonstrations. STMD has selected 38 of these, 26 of which have flown already. A new call was tentatively scheduled for April. Prizes and challenges for

ISS include the Cement Solidification Experiment; the NASA Earth, Air, and Space Prize; and the Vascular Tissue Challenge, planned for the fall in conjunction with the Center for the Advancement of Science in Space (CASIS). SMTD will continue looking for opportunities to use ISS as a testbed for future technologies.

Dr. Mary Ellen Weber noted that CASIS has undergone some changes in name and leadership and wanted to know how that might have affected STMD's relationship with the Center. Ms. Werkheiser said that CASIS has new areas of focus. STMD sends interested companies to them, and the ISS technology demonstration office gets involved in some of these. The changes have made a difference, but there are lots of opportunities. She has had a positive experience with them. Mr. James Oschmann noted that some technology demonstration missions are near the end. He asked about any talk of transfer. Mr. Reuter said that it is part of the plan, and STMD wants to do follow-up.

LSII
Ms. Werkheiser explained that LSII hopes to spur creation of novel technologies for lunar surface exploration, as well as accelerate the technology readiness of key systems and components. Activities will include internal NASA efforts, competitive programs, and public-private partnerships. Having an executable plan is key, so the Agency will employ a range of robust acquisition strategies in order to best engage with the various stakeholders. Initial efforts will focus on the "low-hanging fruit" to get to the 2024 goals for Artemis. The six technology focus areas are: ISRU, surface power, extreme access, surface excavation and construction, lunar dust mitigation, and extreme environments. STMD technology demonstrations will allow the primary technology hurdles to be retired for a given capability at a relevant scale. A big part of what LSII does is ensure that there is a common language with SMD and HEOMD.

Examples of some LSII flight demonstrations include ISRU technology maturation activities, the Polar Resources Ice Mining Experiment (PRIME-1), the Volatiles Investigating Polar Exploration Rover (VIPER), oxygen extraction from regolith, and high-fidelity simulant supply chain assessment. These will culminate in pilot ISRU consumable production systems around FY28. While there are other ISRU activities, and partners want to be able to do full-scale systems, LSII is the lead. For surface power, STMD is developing technologies with the goal of providing continuous power through day and night for lunar surface missions. Ms. Werkheiser listed some of the technology development activities in this area. LSII began work on dust mitigation early, and this will be part of the 2020 SBIR.

The Applied Physics Lab (APL), out of Johns Hopkins University, is the system integrator for LSII. APL established a Lunar Surface Consortium for NASA and academic and industry partners, to address a broad range of capabilities. The Consortium will help NASA identify and determine the readiness levels of lunar surface technology needs; make recommendations for a development and deployment strategy; and provide a central repository of sharable information. The NASA centers all belong, and the Consortium members are learning each other's relative strengths, while also identifying themes. The kickoff was in late February, with over 250 attendees, most of whom had not previously worked with STMD. There were also thousands of online viewers via YouTube and Facebook. The next meeting will take place in the fall.

Flight Opportunities and Small Spacecraft Technology Program Updates
Mr. Chris Baker, an STMD Program Executive, explained that the Flight Opportunities Program facilitates rapid demonstration of promising technologies for space exploration, discovery, and expansion of space commerce through suborbital testing with industry providers. Since technology drives exploration, STMD is going beyond the immediate goals

of Artemis to look at sustainability and moving on to Mars. Partnerships are key. The Program had 15 flights last year, and these technologies are moving into ISS, Artemis, and other initiatives. The four companies selected as CLPS providers leveraged Flight Opportunities-supported suborbital flights to test technologies that are incorporated into their landers and/or are testing lunar landing technologies. Mr. Baker described the successful Astrobiotic auto-landing test conducted by Masten Space Systems, which involved navigation to a safe landing location, including avoidance of mock hazards. The system is being further matured and will be used for the CLPS lander.

Using commercial, off-the-shelf technology, the Radiation-Tolerant Computing System (RadSat) provides a reconfigurable and redundant architecture while also offering self-healing capabilities. NASA's return to the Moon will require radiation-tolerant computing of this sort. RadSat has been selected for further infusion into CubeSat and SmallSat initiatives, and will be a demonstration under the Artemis program. The Orbital Syngas Commodity Augmentation Reactor (OSCAR) is a NASA ECI project to recycle human waste by burning it and breaking it down into reusable chemical sub-components. These examples show what is possible. The Directorate does not fund science investigations, but it does test technology that science investigations can use. Congress has asked for funding to go to education, which STMD is doing. PIs can once again fly along with their payloads, as well.

One area for improvement is the time it takes from lab to flight, which currently averages 21 months. The program is trying to get this down to 9 months now. Similarly, the average interval for reflights for suborbital is 10 months, and STMD is trying to get that below 6 months. The suborbital program has some overlap with the Small Spacecraft Technology program, which seeks to develop and demonstrate small spacecraft for exploration, science, and the commercial sector. Among the objectives of this program are lowering costs, reducing development time, and enabling augmentation of existing assets. Small spacecraft will help determine the risks and possibilities of the terrains and environments on the Moon, Mars, and other destinations.

An examination of mission concepts for small spacecraft highlighted a number of technology gaps in the areas of deep space propulsion, radiation tolerance, deep space navigation, and ISRU and terrain surveying. The mission concepts that were reviewed came from a number of sources; SMD's Planetary Science Division (PSD) put out a call for mission concepts for SmallSats and CubeSats for deep space missions, and those results were examined as the initial set. The team also looked at papers done elsewhere, like at NAS. These mapped against what was needed for science and exploration missions. Mr. Free observed that the needs seemed focused on deep space or planetary. Mr. Baker stated that Earth science is an area in which there has been a proliferation of investments in small spacecraft, and heliophysics uses constellations that could have cis-lunar applications.

There are 22 upcoming demonstration missions, several of which Mr. Baker described. For example, the CubeSat Laser Infrared Crosslink (CLICK) will demonstrate an optical communication crosslink and precision ranging between two CubeSats. The Lunar Flashlight will use a compact laser spectrometer to characterize lunar ISRU potential, with a focus on surface ice deposits in the South Pole. Four of the demonstration missions are public/private partnerships. Mr. Baker then discussed the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission in greater depth. This effort will test autonomous relative navigation for the Gateway and other lunar missions, verify Near Rectilinear Halo Orbit (NRHO) dynamics, and demonstrate novel low-energy transfers to cislunar space, all for less than $30 million and in under three years. CAPSTONE demonstrates rapidity, with the flight hardware due for delivery in late 2020, though the coronavirus situation could affect the schedule.

Mr. Free asked about SMD's contribution. Mr. Baker explained that small spacecraft have roles in multiple mission directorates. SMD invests in the instruments, while STMD invests in the buses, and the two mission directorates coordinate. There is also coordination with SMD on certain SBIR activities. STMD helps frame topic areas and do the reviews. CAPSTONE is an SBIR Phase 3 project.

Office of Chief Engineer Update and Discussion of Processes to Evaluate Technology Implementation

Mr. John McManamen, Chief Engineer in HEOMD, discussed lessons learned from the Commercial Crew Program (CCP). He reviewed the CCP insight/oversight model, which relies on: a lean, minimally prescriptive approach; leveraged partnership processes, standards, and innovation; and shared assurance and accountability. Much of the focus is on safety, hazard controls, and reporting, applying the many lessons that NASA has learned in this area over the years. While there are some reduced standards, alternative approaches are encouraged, and some critical systems have been selected for deeper focus. Although the engineering team has grown over time, it remains lean compared to the traditional insight/oversight model. Concurrence on design certification drove a lot of the work. Design and construction standards discussions and negotiations became a very important tool for the NASA team to leverage in order to gain sufficient insight and to ensure safe and reliable systems. The Engineering Review Board (ERB) enabled broad communication, while the Program Control Board (PCB) was used to make risk-based decisions

Mr. McManamen next described the engineering challenges and resultant actions taken by the engineering team. Catastrophic failures have occurred, and some commercial partners have limited-or-no experience with human spaceflight. Further, these partners have introduced designs that appear to have very limited-to-no data or experience to reference. The question then becomes one of identification of the margins or controls to certify the designs for NASA crew. Dr. Weber said she thought the target for catastrophic failure was 1 in 270 for CCP. Mr. McManamen said that it was, and it is probabilistic. Dr. Weber asked if that number includes mitigation from crew abort systems. Mr. McManamen said that he thought it was separate but would check and get back to her.

He then listed five specific questions or charges to the engineering team, including: identification of examples to be added to the list; whether there exists an adequate review of the technology/analysis for NASA to understand the potential impact to the design; if CCP is controlling critical design parameters via specific mechanisms and what improvements might be added; if NASA or the partners should further test or otherwise address operating constraints; and whether NASA or the partners have researched previous uses/studies of the technology. A matrix of results included 91 entries, spanning multiple systems/subsystems in a number of areas. These are all areas in which there is innovation and people looking for new solutions, but demonstrations are still necessary.

An example is additive manufacturing, a win-win. It involved the extensive use of additive manufactured parts in propulsion system components, and presented a significant benefit to cost, schedule, and design efficiency. This is an area of NASA research and development at Marshall and other centers. It required good collaboration between NASA and the commercial partners, especially given that this maturing capability is intended to be used in critical human space flight applications. Initially, there were no formal NASA standards or guidance in this area, but the Agency and commercial partner developed interim guidelines while continuing to work toward the standards, scheduled to be released over the summer. So far, the team has seen very good parts performance in a range of tests.

The Pusher Escape Systems-Challenging Integrated System is a complex system that is new to human space flight. Both NASA and the commercial partners selected a pusher-type crew escape system, though each took a different approach. While this created some issues, it also resulted in some complementarity. Mr. McManamen reviewed the features. While this is a success story, NASA and the partners are still working through some areas.

Key observations start with the fact that NASA CCP and its partners found many areas of innovation in new technology development, but also encountered challenges that impede flight certification. There is a need to look at the big drivers early in the process. The comprehensive view of the end goal is essential and cannot be left out, as sometimes occurs. Similarly, while NASA is good at the spiral design approach, there are some pitfalls, including the limits from the empirical approach. There is also a hesitancy to lock things down, which results in a blurring of the line between development and qualification. System engineering and integration/process controls are essential but sometimes lacking. While there may seem to be a lot of testing, it is often of components, and things like the fundamental physics of materials, for example, are overlooked, which can be a problem. Without system modeling and analysis, it is not possible to know which tests should be done. This needs to begin early so the models can mature with the hardware. While it has been said that NASA standards stall innovation, those standards enable safe, certifiable flight systems. They also provide a basis from which to start, especially for new companies.

In summary, there were many areas of innovation with NASA's CCP partners, but there were also unintended consequences and issues that served as barriers to flight certification. A rigorous system engineering and integration process is essential, as is an understanding of the fundamental physics that new technology will be experiencing. System modeling is valuable and should be employed throughout the design lifecycle; the appropriate balance for this will not be the same for every system. Standards and guidelines are needed early in the development process in order to reach the end goal of safe and reliable hardware.

Dr. Weber asked how CCP compares to commercial cargo, and whether the latter group is following their original process or if they adopted lessons learned from CCP. Mr. McManamen said that while the risk postures are quite different, commercial cargo still had to consider the safety net of ISS. Nonetheless, NASA did not impose standards and was almost completely hands-off. The initial thought process was to segue from cargo to crew, which proved more challenging than expected. There are huge issues between the two that are not obvious. Having standards helped with the expectations. NASA has still not certified commercial crew. Dr. Weber said that commercial crew was targeted for 2017 and still has not happened. She wondered how this hindsight might have helped meet that target. Mr. McManamen said that Artemis is trying to learn from commercial crew. These are a lot of the lessons learned, around standards, system engineering processes, etc. Setting up standards early is key, and that took years to determine. Artemis has a whole new process. The exercise here was in finding what OCE might have missed. There is a broader set of lessons learned having to do with insight and collaborative efforts. While some of these things might have helped, he cannot say about 2017.

Discussion and Recommendations

Mr. Green asked if there were any additional questions for Ms. Werkheiser. Mr. Free wanted more about the LSII timeline. Ms. Werkheiser said that the work has begun for this 5-year project. The team has set up meetings and is updating contracts for the larger system integrator role. APL has been working with NASA's Glenn Research Center and is now getting extractions of the interface for the assessments. Mr. Johns asked if students are being directed to contribute to student competitions for Artemis. Ms. Werkheiser confirmed that NASA will be working with the winners of both the open source challenges and the student challenges. Other opportunities will be open to students, as well as industry and others. There is an effort to do mentoring. The next challenge is for the small rovers, the scouts, which is a payload challenge. GCD has the "Big Idea" challenge, which will occur every year. It will help students make real world contacts and bring them additional opportunities. Mr. Green added that this is with the NASA Space Grant Consortium and involves a large amount of money.

Mr. Green then asked the TI&E members for observations. Dr. Kathleen Howell said that she noticed a theme of exploring different ways to innovate, which is positive. In the SmallSat world, that offers lots of opportunities. She wanted to congratulate STMD for that. She noted other innovations discussed that day in the area of operations and in engaging and recognizing the contributions of commercial partners. Dr. Weber said that the last presentation was fascinating. It is important for TI&E to be briefed periodically on what is going on with the other mission directorates. She was concerned that the dramatic budget increases might be difficult for STMD from a staffing standpoint. Mr. Reuter said that it might not happen, but it concerns him as well. The budget has doubled in the last 3-4 years, and that could occur again. The steps are big, and STMD is not completely ready to take on this role, as it demands a lot. However, they have gotten approval to modify the organization. He noted the four primary line accounts mentioned earlier. If the budget comes through, then in FY21 or FY22, some of these lines will have as much budget to manage as the entirety of STMD did four or five years ago.

In addition, this is the only mission directorate without another layer between the Associate Administrator and the projects themselves. It is also the only one without a deputy resource manager. But STMD did get approval to add new positions. Mr. Reuter described some of the possible changes, noting that the new structure will add a layer. The announcement was imminent, and some offices, such as GCD and TDM, were being upgraded. Dr. Weber suggested that TI&E write a finding to the full NAC stating that while the Committee is happy with the growth and funding, it is a risk to grow so quickly, and they commend Mr. Reuter's foresight and the steps taken to anticipate this. Mr. Reuter said that that was a reasonable summary of the situation.

Mr. Green noted that this was Mr. Oschmann's last meeting, as he was leaving the Committee. He thanked Mr. Oschmann for his time. Mr. Oschmann said that he has enjoyed it. He thought there were good things presented that day, like the innovation and partnership discussion. He agreed that they did not hear much on activities outside of STMD. He applauds the budget growth and Mr. Reuter's plan to manage it. The last presentation was very good. He would like to emphasize that there are more areas of collaboration outside of that area. There is a lot of technology development in SMD, for example. The TI&E purview should include that kind of thing.

Mr. Johns said that there has been a lot of progress in these program areas, more than in previous years. Mr. Reuter gets much of the credit, along with the robust and growing budgets. He liked hearing the lessons learned. However, he was still not clear on the nuclear propulsion strategy and where NASA is going with that. The Committee had a previous presentation on kilopower, and it might be good to have a similar presentation on nuclear power. He also appreciated STMD's support for early career professionals. Finally, he was concerned that SBIR/STTR budget growth could present problems. Mr. Reuter explained that they need Congress to help out on this. There are different models within DOD. Regarding nuclear propulsion, there are a lot of things going on in parallel, such as internal NASA studies, Congressional direction to do a flight demonstration with industry, and DOD and DARPA activities. A lot of studies will be completed soon, and there is the longer term NAS study as well. STMD is not ready to do is the flight demonstration. They can work on concept studies, but the most fundamental issue is that they are being pulled in different directions.

Dr. Howell observed that the LSI Consortium is a new type of model for NASA, with a balance among academia, industry, and NASA. She hopes to hear of the internal assessments of how this model works and how it might be applied elsewhere. Mr. Reuter agreed, stating that there is strong interest across a broad community to investigate and operate on the lunar surface, especially by universities and small business. He noted the workshop and survey. Dr. Howell said that there is still uncertainty among those who attended as to what the outcomes are to be.

Mr. Free said the Committee would keep LSII as a regular agenda item, as it is a 5-year effort and has the lunar focus. He would also keep nuclear propulsion on the agenda. Dr. Weber had suggested making a statement to the NAC about continued protection of the budget as STMD adds these big programs, and Mr. Free thought that was a good idea. He would like to see the new organizational structure at the next meeting and hear about the management challenges. Another topic he would like to explore in more detail is the next big wave relating to Mars surface technology. He hopes to make OCE an active agenda item, as it falls under TI&E's purview, and he would also like to see how the Office can help STMD and other NASA elements. Things are well-aligned within and outside of STMD, and it is fascinating to see the results, like the flight opportunities turning into infusion. The budget is there to build big things, but the faith in the budget is there because of the results STMD has had. The process of getting the results could be disseminated.

Mr. Green asked if there were any findings beyond Dr. Weber's on the organization in light of increased budget growth. He suggested that nuclear technologies be expanded upon at the next meeting so that TI&E could provide more feedback. Mr. Free agreed, citing surface power and NTP. He worries about the possibility of having too much mission analysis. The NAC has a general awareness of everything nuclear that STMD is looking at, including the surface power mission, NTP, NEP/NTP trades, and the technology development in terms of conjunction missions and opposition missions. It is good to raise the awareness of the NAC. He liked Mr. Johns' idea of talking about nuclear technologies, since there are so many contributors. Mr. Green observed that the need for a national strategy is becoming more apparent. Mr. Reuter said that the Office of Science and Technology Policy (OSTP) is developing a national strategy that talks about roles and responsibilities. NASA has direct representation from STMD and SMD.

The Committee would try to have an SMD presentation on that mission directorate's technology development efforts at the next meeting. Mr. Free asked that TI&E members send their specific ideas for slides to him and Mr. Green, who would assemble something and run it by the members for edits. He appreciated the information from the presentations and the time it took to develop it. Mr. Reuter added that there was a lot of background information in the presentations. Mr. Green thanked the members for being accommodating and said that he hoped for a late summer, face-to-face meeting. If that is not possible, they would do another teleconference.

Adjournment
The meeting was adjourned at 4:32 p.m.

Appendix A

Agenda

NAC Technology, Innovation, and Engineering Committee Meeting
March 19, 2020
NASA Headquarters
Virtual Meeting

March 19 – FACA Public Meeting - Virtual

11:00 a.m.	Welcome and Overview of Agenda/Logistics Mr. Mike Green, Executive Secretary
11:05 a.m.	Opening Remarks Mr. Jim Free, Chair
11:15 a.m.	Space Technology Mission Directorate (STMD) FY 2021 Budget Proposal and Update Mr. James Reuter, Associate Administrator, STMD
12:30 p.m.	Space Technology on ISS Update and Lunar Surface Innovation Initiative (LSII) Update Ms. Niki Werkheiser, Program Executive and LSII Lead, STMD
1:30 p.m.	Hatch Act Ethics Briefing Ms. Kathleen Teale, Attorney, NASA Office of the General Counsel
1:45 p.m.	Break
2:00 p.m.	Flight Opportunities and Small Spacecraft Technology Program Updates Mr. Chris Baker, Program Executive, STMD
2:45 p.m.	Office of Chief Engineer Update and Discussion of Processes to Evaluate Technology Implementation Mr. John P. McManamen, Chief Engineer, Human Exploration & Operations Mission Directorate
3:30 p.m.	Discussion and Recommendations
5:00 p.m.	Adjournment

APPENDIX B

Committee Membership

Mr. James Free, *Chair*
Mr. G. Michael Green, *Executive Secretary*
Dr. Kathleen C. Howell, Purdue University
Mr. Michael Johns, Southern Research Institute
Dr. Matt Mountain, Association of Universities for Research in Astronomy
Mr. Jim Oschmann, Ball Aerospace (retired)
Dr. Mary Ellen Weber, Stellar Strategies, LLC

APPENDIX C

Presentations

1) STMD Update [Reuter]
2) Space Technology on ISS Update [Werkheiser]
3) Lunar Surface Innovation Initiative (LSII) Status [Werkheiser]
4) Flight Opportunities and Small Spacecraft Technology Program Updates [Baker]
5) OCE Update/Discussion on Processes to Evaluate Technology Implementation [McManamen]